Validation of PhotoStress® Method for Stress Analysis on a Pipe Spool

Authors:

MM Matrix Integrity (M) Sdn Bhd
M.A. Che Jafri, Structural Integrity Engineer
F. Zolkifeli, Structural Integrity Engineer
M. Abd. Murad, Technical Advisor / Founder

PETRONAS Group Technical Solutions
A.H. Mohamad, Principal Piping Engineer

MM Matrix Integrity (M) Sdn Bhd invited PETRONAS Group Technical Solutions to observe a demonstration of the PhotoStress® method. The demonstration's purpose was to confirm that the PhotoStress® technology is reliable for measuring surface strain at defect and away from the defect areas (nominal). Qualitative and quantitative analyses were performed on a carbon steel pipe spool, and results were validated against strain gage readings and empirical values.

Company/Institute: MM Matrix Integrity (M) Sdn Bhd
PETRONAS Group Technical Solutions

Industry/Application Area: Oil & Gas Industry – Experimental Stress Analysis (Piping)

Products Used:

- PhotoStress® Plus
- PL-1 Photoelastic Coating
- PC-1C Adhesive
- Uniaxial Strain Gages
- P3 Strain Indicator and Recorder

The Challenge

Strain gage measurement is limited to localized areas whereas finite element analysis is sometimes more costly. With the PhotoStress® Method, the strain distribution on a test surface is easily observed and measured in under real conditions.

The demonstration was performed to prove the reliability of utilizing the PhotoStress® method for measuring surface strains at defect and away from the defect areas (nominal). The test part used was a 4-inch carbon steel pipe spool run on a pneumatic system.

The Solution

The PhotoStress® analysis is composed of a reflection polariscope and PSCalc® computer software that enables users to store and process LF/Z-2 readings of stress and strain. A variety of photoelastic coatings may be applied on a wide range of materials, including simple or complex shapes. PL-1 photoelastic coating and PC-1C adhesive were used for this case study and applied during unloaded conditions. PhotoStress® values were measured from unloaded conditions, and the pressure was increased from 0 bar (gage) up to 15 bar. Then, the strain values were compared against strain gage readings and empirical values.

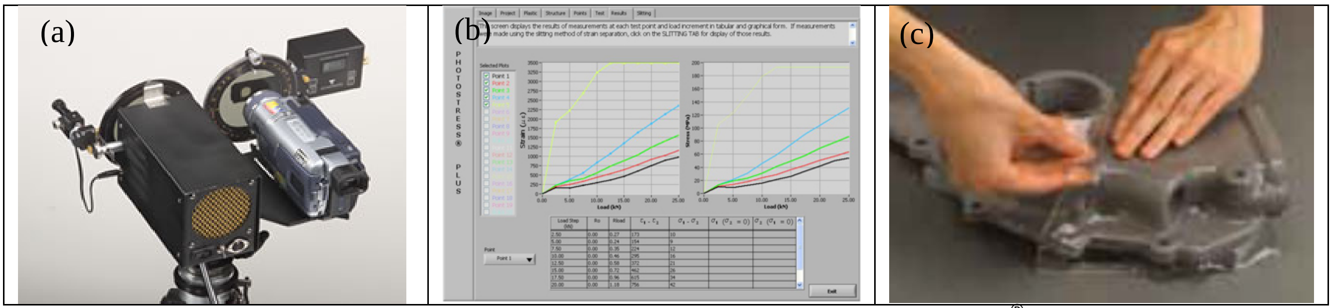


Figure 1: (a) LF/Z-2 reflection polariscope. (b) PSCalc software. (c) PhotoStress® coating applied to a structure of complex shape.

The carbon steel, schedule 40 pipe spool with approximately 1.2 m in length was divided into three sections. Photoelastic coating was applied in the middle section whereas strain gages were installed at the end section of the pipe.

Table 1: Carbon steel pipe specifications

Pipe schedule	SCH 40
Nominal thickness, t (mm)	6.02
OD (mm)	114.3
Poisson’s ratio	0.29
Modulus, E (MPa)	209,000

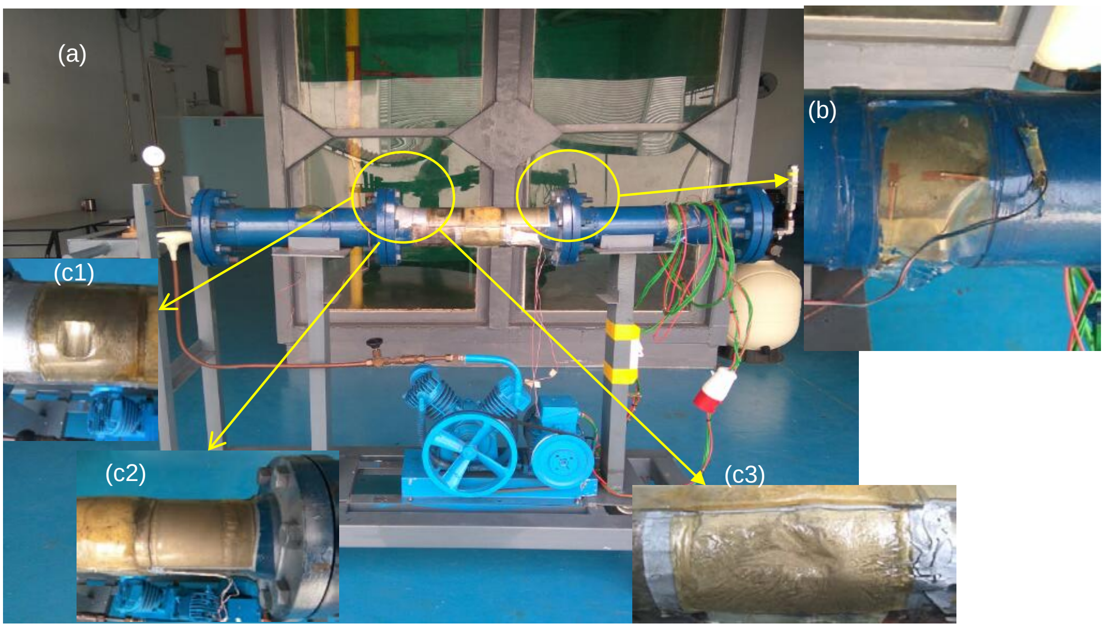


Figure 2: (a) Pipe spool (b) Strain gage to measure hoop strain (c1) Photoelastic coating on Location 1 (c2) Photoelastic coating on Location 2 - a nominal thickness, and (c3) Photoelastic coating on Location 3 – defect in the composite wrapping

The User Explains

Strain Value

The results obtained from the PSCalc® software were tabulated, plotted and compared against strain gage and empirical values, as shown in Table 2 and Figure 3 below.

<u>Empirical</u>

Hoop stress

$$\sigma_h = \frac{PD}{2t} \tag{1}$$

Hooke's Law

$$E = \frac{\sigma}{\varepsilon} \tag{2}$$

By combining equations (1) and (2), the strain value is given by:

$$\varepsilon = \frac{PD}{2Et} \tag{3}$$

Table 2: Strain values from PhotoStress® and strain gage measurements, and empirical data

Pressure (bar)	PhotoStress® (με)	Strain Gage (με)	Empirical (με)
3	11	9	13
6	23	20	27
9	34	30	40
12	48	42	55
15	59	53	68

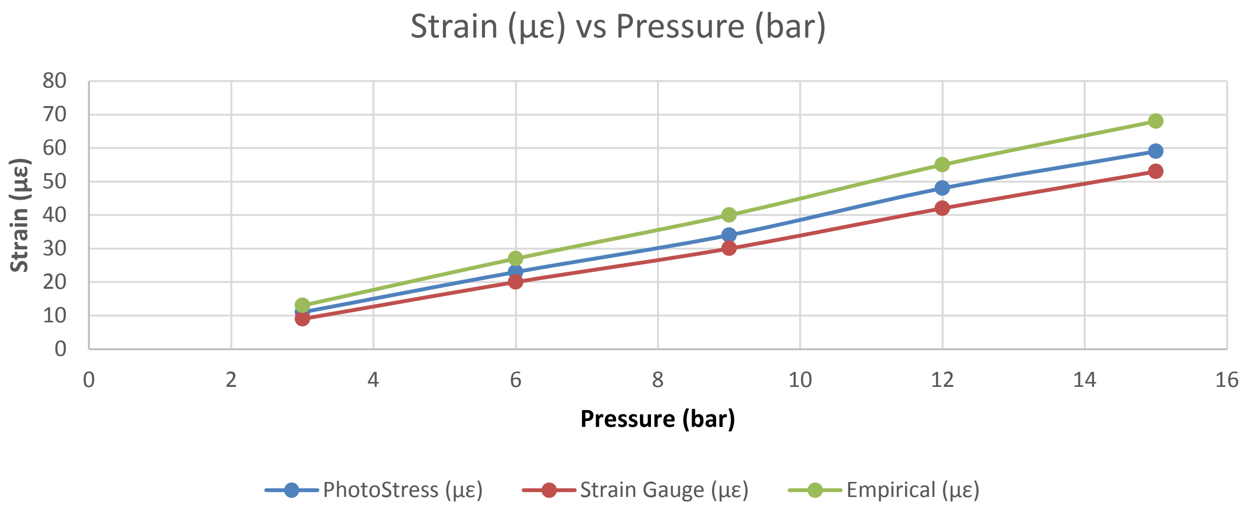
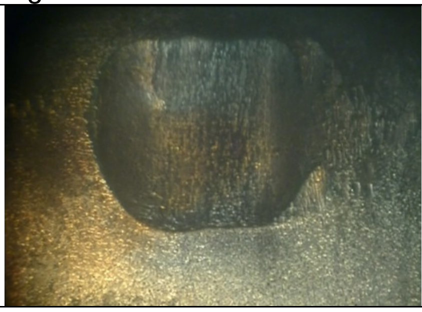
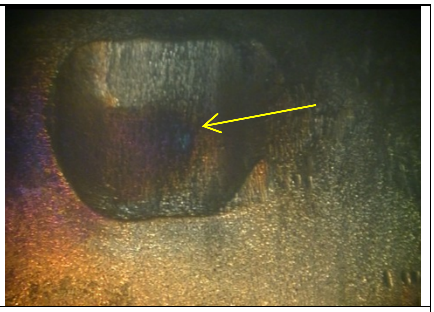


Figure 3: Strain values obtained from the three methods

Figure 3 shows a linear relationship of the strain values obtained from PhotoStress®, strain gage and empirical techniques or methods as the test was carried out in the elastic region. Empirical values were the highest, followed by PhotoStress® and strain gage values. This is because the instant of applicability of empirical method is always based on the ideal condition.

Fringe Patterns

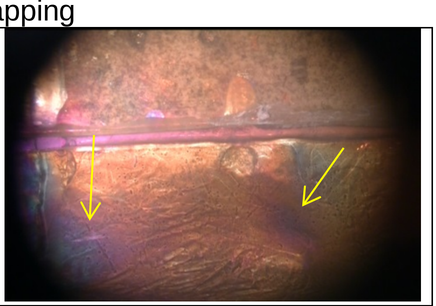
Location 1 / C1. Photoelastic Coating

		
Initial condition at no load condition.	Pale yellow fringe is observed but cannot clearly locate the high stress concentration area.	Blue fringe emerges at the notch in the defect – shows the highest stress concentration area when there is a significant load effect.

Location 2 / C2. Photoelastic Coating —A Nominal Thickness

		
Initial condition (at zero loading).	Pale yellow fringe emerges uniformly as pressure increases.	The fringe pattern changes from the left side and uniformly moves to the right side of pipe.

Location 3 / C3. Photoelastic Coating– Defect in the Composite Wrapping

		
Initial condition (unloaded condition).	Pale yellow fringe pattern appears as compensator values increases.	Blue fringe emerges at the dented area and left side.

From the experimental techniques, i.e., PhotoStress® and strain gage applications, the component stress analysis is very close to the real behaviour because these two techniques do not need to simplify the geometry, loads or constraints. However, strain gage measurement is limited to a localized area only, whereas photoelastic coating is able to show the overall strain distribution through an informative colorful pattern or birefringence throughout the coated area. Based on the test results, a fringe color was observed only in the range of pale yellow when the maximum test pressure achieved was limited to 15 bar. As expected, the highest strain value was considerably low and more or less same as the value derived from the empirical formula. The difference between PhotoStress® and strain gage values are between 2 – 4 $\mu\varepsilon$ only. Note: Finite element analysis can be performed further for extensive comparison in the future.

Based on our results, there was no significant difference in fringe color, i.e., the fringe color was pale yellow only, when the pressure was increased up to 15 bar. Thus, the compensator value was increased first to observe the area of high concentration. Blue fringe color was noted at the location that had the highest stress concentration. The fringe pattern emerged uniformly on the pipe nominal surface area (non-defect area) at Location c2. However, the fringe pattern emerged as a scattered pattern at the defect areas at Locations c1 and c3. This phenomenon indicates that there was a stress gradient at these locations and localized regions that were overstressed.

The PhotoStress® method is an experimental stress analysis technique. Full distribution of the strain or stress can be easily observed in the coated area. However, the PhotoStress® method requires some clinical techniques or processes and skilled operators and it is also subject to load effects conditions. Hence, sensitivity of the photoelastic coating plays an important role to locate and measure high strain in low pressure condition. Quantitative measurement can be performed using the electronic compensator in determining the strain and stress values. This technique can be verified by strain gage and FEA methods.

“With PhotoStress® method, the strain distribution on a test surface can be easily observed and measured in real conditions.”

Acknowledgement:

MM MATRIX INTEGRITY (M) SDN BHD was one of the leading Bumiputra and PETRONAS licensed companies.
The PhotoStress® method is an experimental stress analysis technique. The full distribution of the strain or stress can be easily observed in the coated area. However, PhotoStress® requires some clinical techniques or processes and skilled operators and it is also subjected to load effects condition. Quantitative measurement can be performed using the electronic compensator in determining the strain and stress value. The results were validated by comparison between the analytical and strain gauges readings which show the same trend with a slight difference of strain data. We hope this new technology will be able to help us to extend the PhotoStress® method application and research in the field, especially on piping and composite wrapping in PETRONAS assets with support from PETRONAS Group Technical Solutions.

Contact Information

Muhamad Adib Bin Che Jafri
Structural Integrity Engineer
MM Matrix Integrity (M) Sdn Bhd
Selangor, MALAYSIA.
Web: www.matrixintegrity.com

Faizal Zolkifeli
Structural Integrity Engineer
MM Matrix Integrity (M) Sdn Bhd
Selangor, MALAYSIA.
Web: www.matrixintegrity.com

Ir. Dr. Mahadi Abd Murad
Technical Advisor / Founder
MM Matrix Integrity (M) Sdn Bhd
Selangor, MALAYSIA.
Web: www.matrixintegrity.com

Vishay Precision Group, Inc. (VPG)
Micro-Measurements®
mm@vpgsensors.com